BIOMECHANICS AND PRODUCT DEVELOPMENT IN ERGONOMICS

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This study introduced an ergonomic product development process consisting of eight stages of needs assessment, ergonomic guideline, anthropometry, brainstorming and idea sketch, preliminary model, drafting and rendering, working prototype, and user trials. As the instances of using biomechanics in the stage of user trials to reduce physical stress of product users, it also illustrated four case studies on clamping hand tool, laparoscopic surgical tool, drum washer, and wheeled luggage. The case studies utilized several biomechanical techniques covering direct force measurement with load cells, electromyography (EMG) for muscular force and fatigue estimation, and three-dimensional inverse dynamic model for joint reaction force and moment estimation.

KEYWORDS: biomechanics, ergonomics, product development

INTRODUCTION:

Both sports science and ergonomics use the interdisciplinary scientific area of biomechanics for their own purposes, but interpreting its results seems somewhat opposite. Sports science focuses on specific populations, such as national athletes, who try to make new records, and biomechanics is contributed to enhancing their capabilities for more strength, distance, accuracy, etc. under strict game rules. Ergonomics instead focuses on all populations including the elderly, the disabled, and children, and biomechanics is applied to identify their limitations under which they can work and use products in their own preferred ways. Thus the objective of this study is to introduce how biomechanics can be used to develop products with a development process and case studies in ergonomics.

PRODUCT DEVELOPMENT PROCESS:

A typical process of ergonomic product development consists of needs assessment, ergonomic guideline, anthropometry, brainstorming and idea sketch, preliminary model, drafting and rendering, working prototype, and user trials. As indicated in the title, needs assessment mainly involves the subjective methods of observations, questionnaires, interviews, checklists, and expert appraisals to find what users want. A plenty of ergonomic guidelines on product design are available in the literature for potential products to be developed that are found in needs assessment. Product dimensions are determined by fundamental anthropometric data of length, width, thickness, and circumference. Brainstorming and idea sketch integrate information collected in the first three stages and can simply make imagined products real with pen and paper in two dimensions. Preliminary model is the first physical three-dimensional model for continuous refinements. Product drafts are made with a computer-aided design (CAD) system based on the preliminary model and rendering illustrates a computer model useful for discussing with users. Working prototypes can be built with various manufacturing methods. Biomechanics is used in user trials that is considered the most informative method as an objective evaluation rather than the subjective methods mentioned in needs assessment (Shin, Kim, Hallbeck, Haight, & Jung, 2008)

CASE STUDIES:

Four case studies are introduced on clamping hand tool, laparoscopic surgical tool, drum washer, and wheeled luggage as the examples of ergonomic product development using biomechanics in user trials. The application of the process is explained in detail only for the first case study on clamping hand tool due to redundancy.

Clamping Hand Tool: The issue on handle redesign was arose for a commercially available clamping hand tool (Quick-Grip® Bar Clamp, Irwin Industrial Tools Company) by ergonomic expert appraisals because of inappropriate handle shape and size (Figure 1). Ergonomics and anthropometry suggested a flanged circular handle with no grooves and indentations whose opening ranges and length are 5 cm to 10 cm and 12.5 cm, respectively. The overall and specific design concepts of a new handle was sketched during a brainstorming session, and a preliminary model was made with balsa wood. A working prototype was built by a rapid prototyping technique after drafting and rendering (Jung & Hallbeck, 2005; Shin, Kim, Hallbeck, Haight, & Jung, 2008).

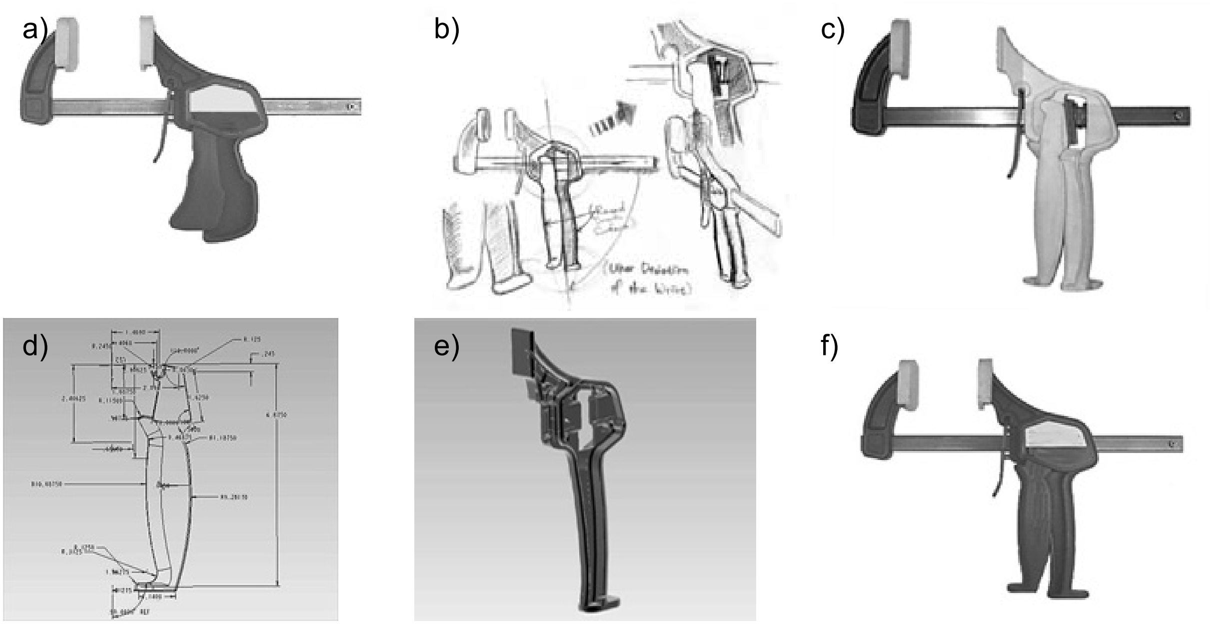

Figure 1. Ergonomic product development process for clamping hand tool handle redesign: a) original handle, b) idea sketch, c) preliminary model, d) draft, e) rendering, and f) working prototype

Twenty participants performed 24 clamping tasks with both existing and new tools in order to measure handle-squeezing and object-clamping forces collected by installing load cells. The new tool reduced 25% less handle-squeezing force but even increased 21% more object-clamping force due to longer moment arm of the new handle than that of the existing handle (Figure 2).

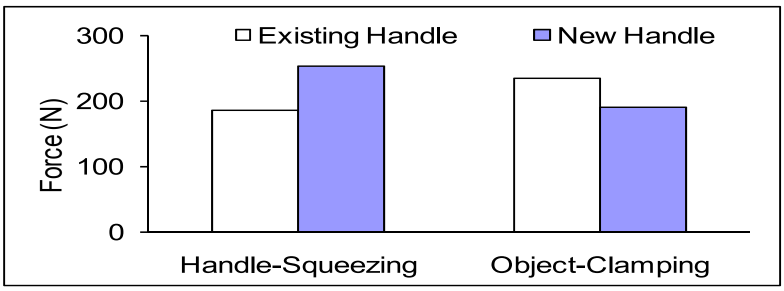

Figure 2. Comparison between existing and new handles for handle-squeezing and object-clamping forces

Laparoscopic Surgical Tool: Laparoscopic surgery exposes surgeons to a high risk of post-surgery discomfort and pain in the hand and arm because of longer duration of operation and more poorly designed tools than those of open surgery. Following the product development process, a new laparoscopic surgical tool of a scissor-type grasper was developed and compared with an existing tool in user trials (Figure 3).

The comparison was made by 30 participants each inserting the tools to a simulated abdomen in 50 different ways to evaluate any differences in physical stress between the two in terms of arm posture and muscular effort. Wrist and elbow angles were collected during the experiment with two biaxial electrogoniometers at a sampling rate of 50 Hz after calibration (Biometrics System). Similarly, six channels of surface electromyographic (EMG) electrodes were attached to the muscles of wrist flexors, wrist extensors, biceps brachii, triceps brachii, deltoid, and upper trapezius. A measure of root mean square (RMS) was acquired at a sampling rate of 1000 Hz for muscular effort estimation.
Statistical analyses showed that wrist flexion angles significantly reduced with the new tool about 71% less than with the existing tool because the former provided more maneuverability to the participants in their preferred tool-holding ways than the latter with which the participants should insert their fingers into the loops. Muscular effort did not differ between them with about 20% of maximal muscular activity (Trejo, Jung, Oleynikov, & Hallbeck, 2007).

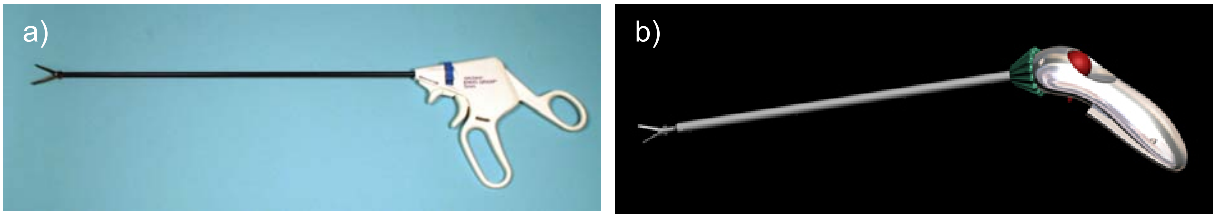

Figure 3. Laparoscopic surgical tools of scissor-type grasper: a) existing tool and b) new tool

Drum Washer: For a marketing purpose, two models of existing and new washers were compared by 10 housewives to identify any reduction of physical stress in use of the new model. Each participant repeated the tasks 6 times seen in Figure 4. The joint angles of the neck, waist, right and left shoulder, right and left elbow, right and left hip, and right and left knee were collected with six cameras of Vicon MX-3+ system by attaching 14 mm markers to 41 anatomical landmarks. Muscular force and fatigue were also estimated with the measures of RMS and mean power frequency (MPF) by attaching six surface EMG electrodes to right splenius capitis, right erector spinae, right and left deltoid, and right and left rectus femoris.

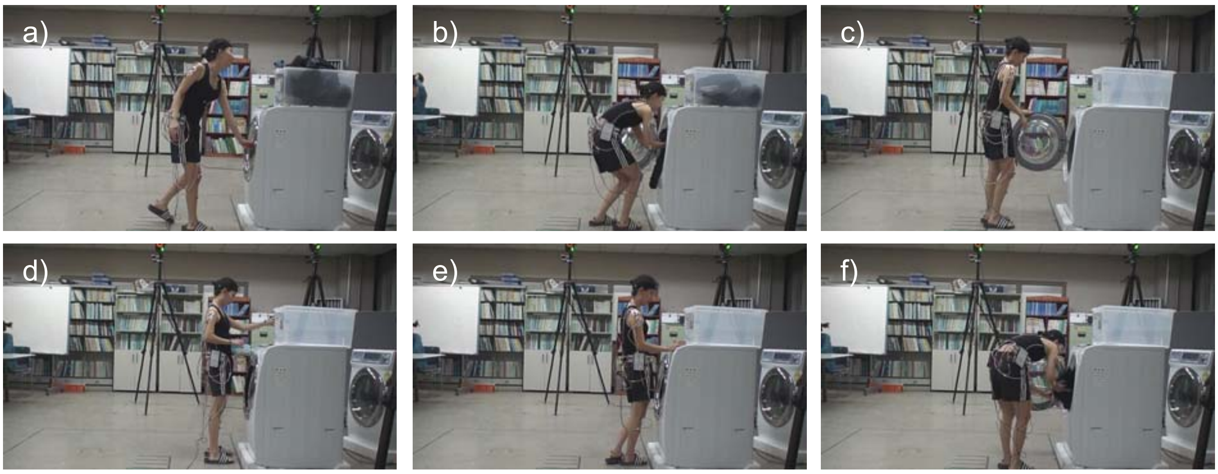

Figure 4. Six washer-using tasks: a) opening door, b) inserting laundry, c) closing door, d) putting detergent, e) setting up laundry course, and f) removing laundry

Overall, repetitive use of washers caused more severe physical loads in the arms than in the other body parts; however, the new model reduced about 12% less muscular force and fatigue because it had a raised door close to the top on which both control panel and container for detergent were placed so that the housewives could use the new model relatively in a standing posture.

Wheeled Luggage: The goal of the last case study on wheeled luggage was somewhat different from those of the other case studies. Though carry-on style two-wheeled luggage has been popular among manual vehicles in daily life, there were no ergonomic guidelines on luggage design.
Thus 4 participants pulled a luggage prototype built with a steel and aluminum frame that could be configured according to the experimental conditions of two levels of handle height (100 cm and 110 cm), two levels of handle rotation (0° and 90°), pole angle (0° and 10°), wheel diameter (8 cm and 15 cm), load weight (15 kg and 23 kg), center of mass (low and middle), and carpeting (no and yes). Joint reaction forces and moments were calculated by developing a three-dimensional inverse dynamic biomechanical model for luggage-pulling tasks in a similar experimental setup to the drum washer case study.
The statistical results concluded that the arms of luggage users were mainly stressed by this type of tasks, and recommended long handle, rotated handle, angled pole, large wheel as luggage design guidelines. In addition, luggage users should carry small amount of belongings on the non-carpeting floor, locating heavy belongings close to the wheels (Jung, Haight, & Freivalds, 2006; Jung, Haight, & Hallbeck, 2007).

Figure 5: Luggage testing prototype for experiment

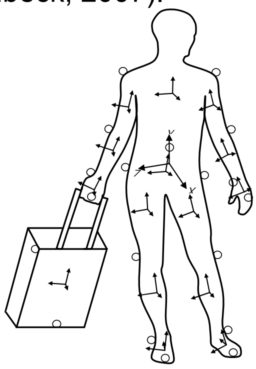

Figure 6: Three-dimensional inverse dynamic model for luggage-pulling tasks

CONCLUSION:

This study introduced four case studies on clamping hand tool, laparoscopic surgical tool, drum washer, and wheeled luggage as the examples of using biomechanics in the user trials of the ergonomic product development process. Several biomechanical techniques covering simple force measurement with load cells, electromyography for muscular force and fatigue estimation, and three-dimensional inverse dynamic model for joint reaction force and moment estimation were utilized to reduce the physical stress of product users by improving usability. Somewhat different ergonomic approaches in use of biomechanics may be helpful to develop user-centered sporting and leisure products in sports science.

REFERENCES:

Jung, M.C., & Hallbeck, M.S. (2005). Ergonomic redesign and evaluation of a clamping tool handle. *Applied Ergonomics*, 36, 619-24.

Jung, M.C., Haight, J.M., & Freivalds, A. (2006). Luggage-pulling task evaluation by kinematics and subjective ratings. *Journal of Safety Health and Environmental Research*, 3, 1-34.

Jung, M.C., Haight, J.M., & Hallbeck, M.S. (2007). Biomechanical and physiological analyses of a luggage-pulling task. *Industrial Health*, 45, 756-65.

Shin, D., Kim, J.Y., Hallbeck, M.S., Haight, J.M., & Jung, M.C. (2008). Ergonomic hand tool and desk and chair development process. *International Journal of Occupational Safety and Ergonomics*, 14, in press.

Trejo, A., Jung, M.C., Oleynikov, D., & Hallbeck, M.S. (2007). Effect of handle design and target location on insertion and aim with a laparoscopic surgical tool. *Applied Ergonomics*, 38, 745-53.